Tevatron Beam Position Monitor Upgrade

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(for the Tevatron BPM Upgrade Project)

PAC05, Knoxville, TN

May 16-20, 2005

Outline

- **Motivation for TeV BPM Upgrade**
- **TeV BPM Upgrade Design and Implementation**
- **Performance of New BPM System**
- **Conclusions**

Motivation for Upgrade

- **Old Tevatron BPM electronics was not accurate, precise or reliable enough for the Tevatron, nor was it able to measure pbar positions.**
  - Old system was built in the early 1980's and is showing its age.
  - Resolution of 150 microns.
  - Uses old networking/controls protocols
  - No pbar position measurements.
- **Pickups in the tunnel not to be modified!**

New System Requirements

- **Stable, accurate, precise measurements.**
  - Aiming for <10 micron (1 sigma) precision for best proton position measurement.
- **Reliable hardware and software.**
- **Software to collect and use the data.**
- **Measurement of antiproton positions (new capability).**
  - Requires that both ends of pickups be instrumented (twice as many electronics channels).
  - Turn-by-turn (wide-band) and close orbit (narrow-band) position measurements

Key Specifications (Protons):
Measurement Range: $\pm$15mm
Absolute Position Accuracy: < 1.0 mm
Long Term Position Stability: < 0.05 mm
Best Orbit Position Resolution: < 0.02mm
Position Linearity: < 1.5%
Relative Position Accuracy: < 5%
Intensity Stability: < 2%

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Relative Position Accuracy: < 5%
Intensity Stability: < 2%

System Design

- ## Schedule:
  - To be effective and useful, the BPM upgrade had to be accomplished quickly.

- ## Technology:
  - A decision was made to use essentially the same digitizer board (made by Echotek Corp.) as was used in the Recycler BPM upgrade.
  - This board was also chosen for the NUMI, transfer line, and Main Injector BPM upgrades.

System Design

- ## Position measurement
  - The 53 MHz component of the BPM response is used to measure position.

- ## Analog signal
  - The analog signal is filtered and attenuated on a special purpose filter board. The bandpass filters are 53 MHz with width of 7 MHz.
  - An impulse response time of 400ns was required to allow for pbar measurements using timing (rather than proton signal subtraction)
    - See Poster/Paper from Bob Webber for details of the timing technique.

System Design

- **Anti-proton position measurements:**
  - The pickups in the Tevatron have directionality of 26dB.
  - Both ends are read out with the new Tevatron BPM electronics.
  - The proton signal (currently) is significantly larger (factor 10) than the antiproton signal.
  - Even with the 26dB directionality, the antiproton ends of the pickups see approximately equal contributions from antiproton and proton and we need to separate them to make antiproton measurements (in frequency space).
    - See Rob Kutschke's poster/paper for details of the proton cancellation technique.

Block Diagram – vertical BPM

53MHz Bandpass Filter +attenuator

Signal Processing

Pickups in tunnel

One pair for p, one for pbar

A/D DDC RAM

A/D DDC RAM

MVME 2400

Filter Board

Echotek

Controls, Plots, Applications

VME Crate Layout

Echotek Boards

CPU   **Timing Card**

PMC
UCD

Tevatron Filter Boards

Proton Signals

E3 House in the Tevatron

Pbar Signals

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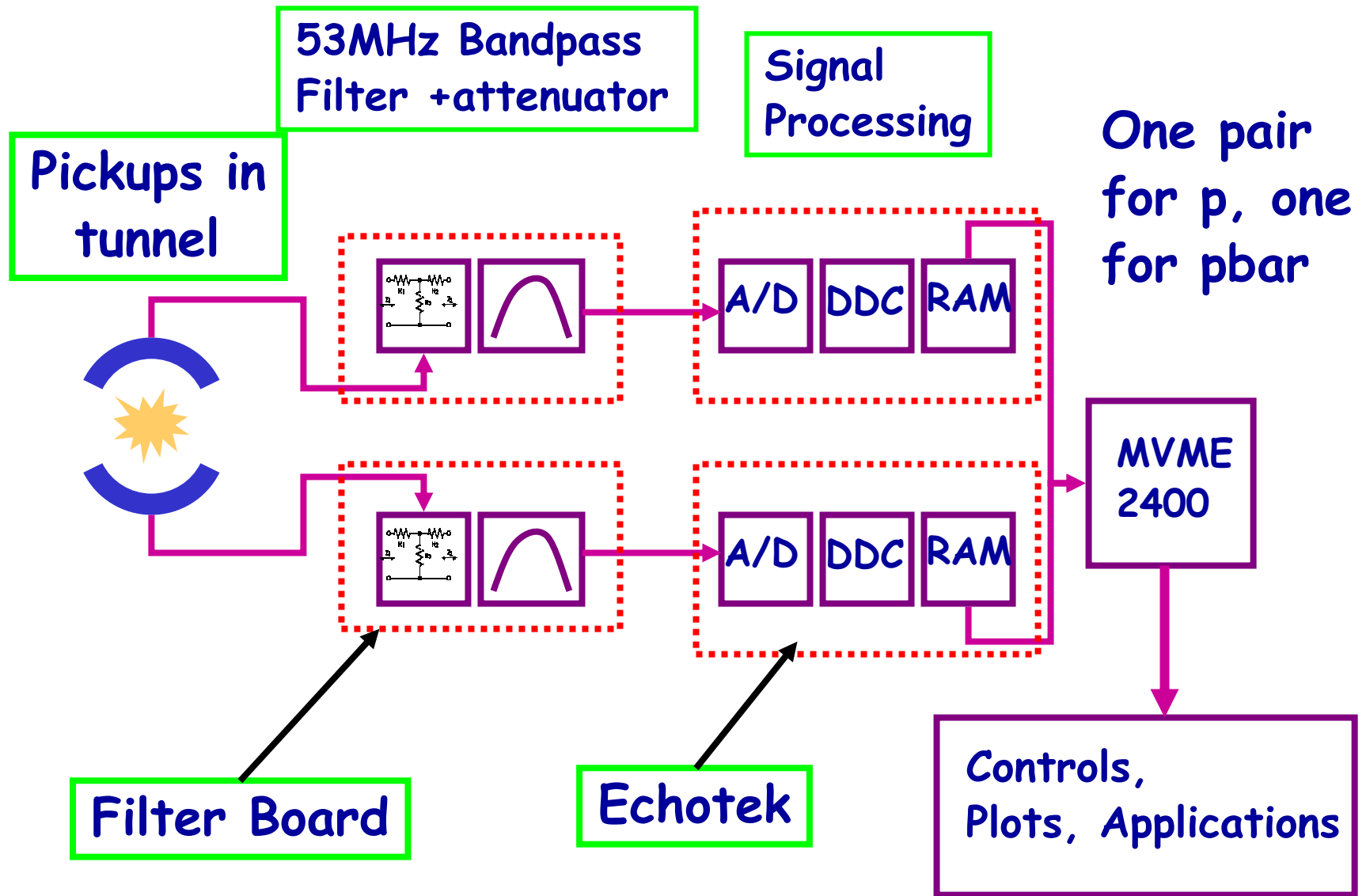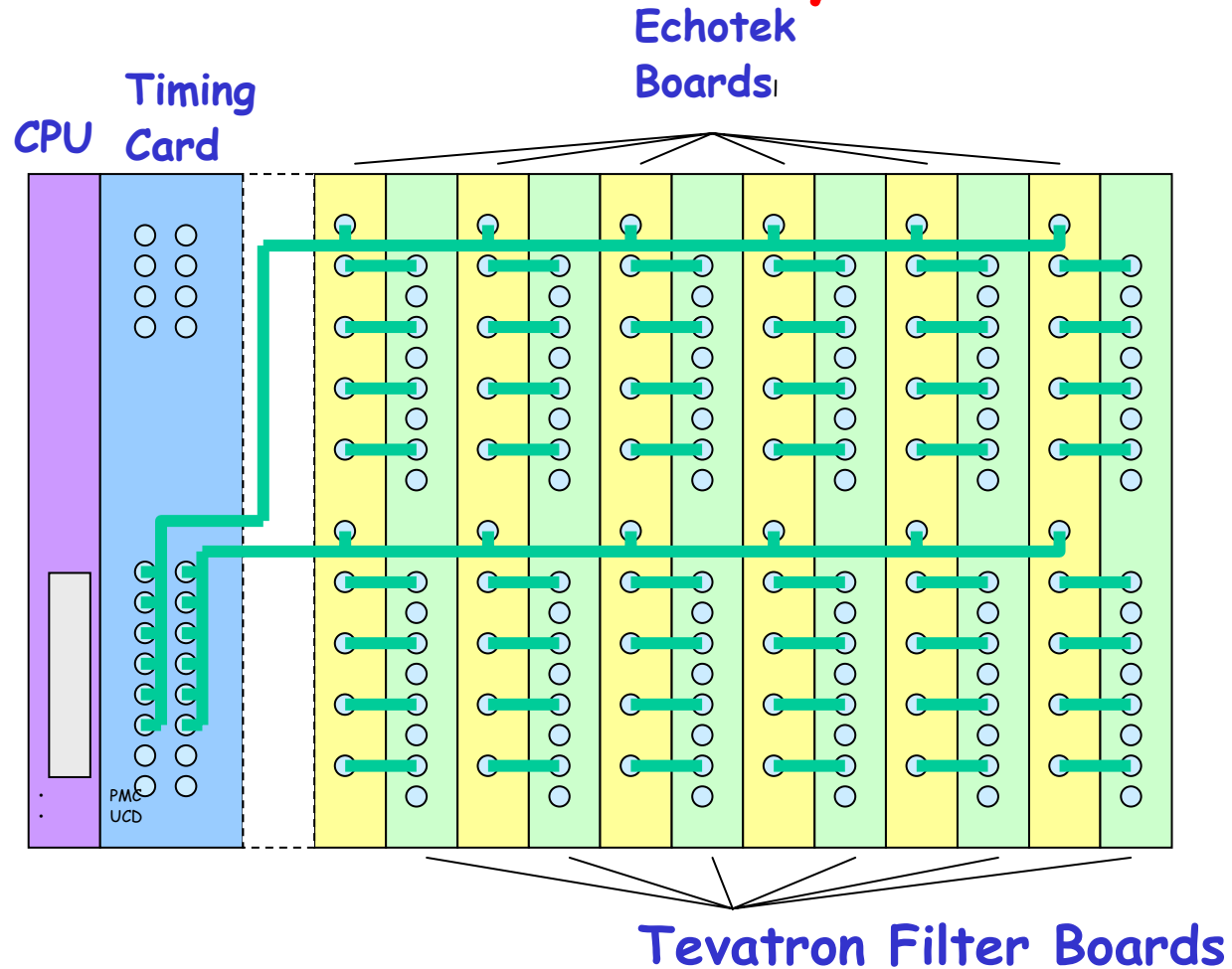
Project Dates

- **9/22/03: Requirements review**
- **12/19/03: Technology choice review**
- **3/11/04: Place Echotek Order**
- **5/14/04: Electronics Design Review**
- **8/20/04: First Production Echotek boards arrive**
- **8/6/04: Install prototype crate in Tevatron**
- **11/23/04: Install first production system in A3**
- **2/7/05: Finish commissioning A3**
- **5/15/05: Finish commissioning all 27 systems**

Commissioning of Houses
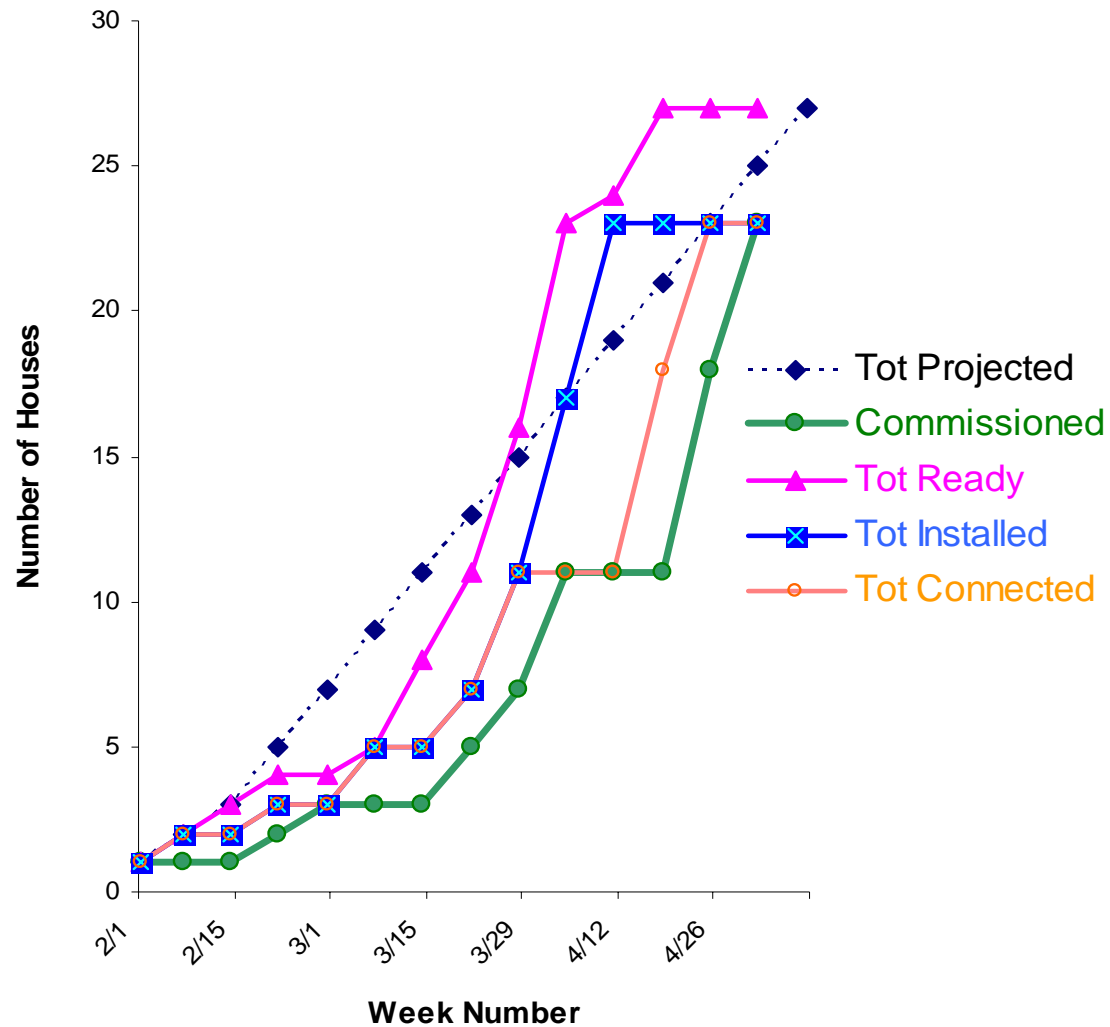
System Performance

- ## Closed orbit
  - Average over all bunches and over many turns (1 KHz bandwidth)
  - Proton and anti-proton positions
  - Best resolution $\sim 7\text{-}10\ \mu$m
  - Vertical BPMs show better resolution
    - This is thought to be due to beam motion in the horizontal plane

Closed Orbit HA32 Shot on Feb 18, 2005

Proton Sum vs time   (1/15 sec)

Proton Position vs time   (1/15 sec)
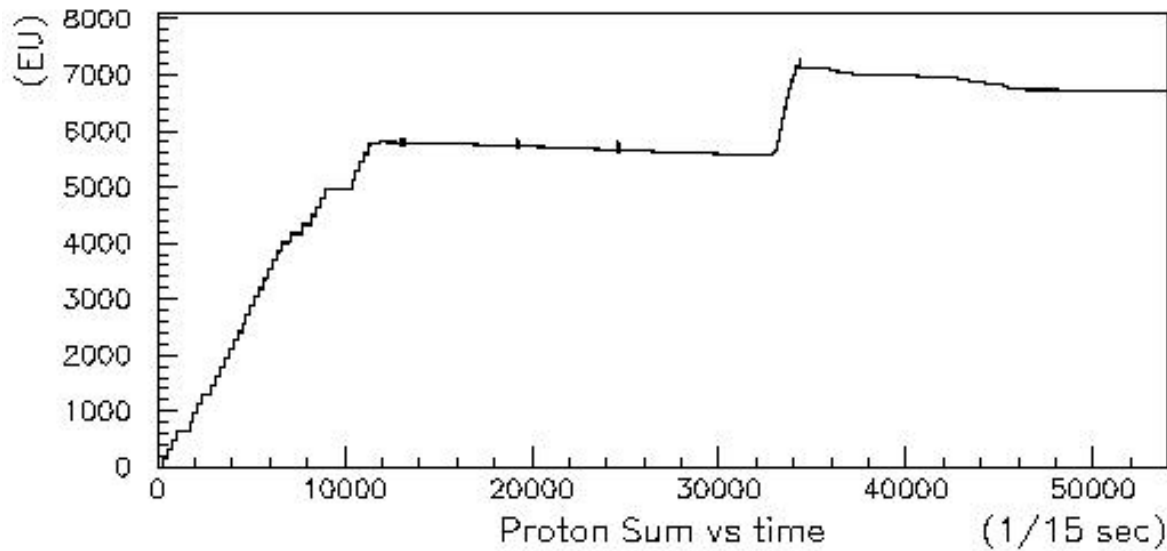
$$Sum = |A| + |B|$$

$$A = (I_A, Q_A)$$

$$B = (I_B, Q_B)$$
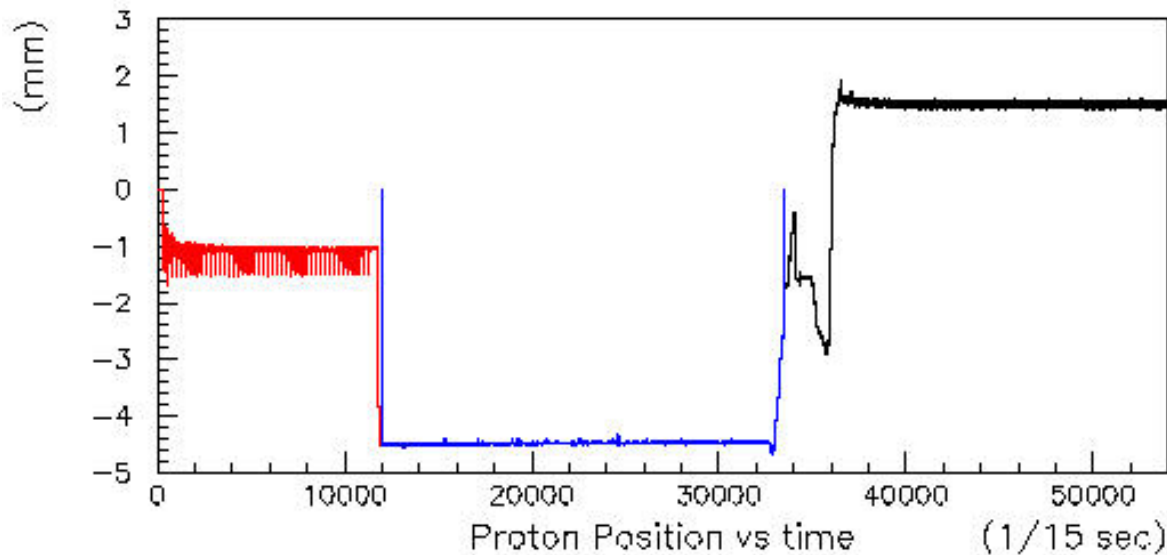
$$P = 26 \frac{|A| - |B|}{|A| + |B|}$$

Closed Orbit HA32 Shot on Feb 18, 2005
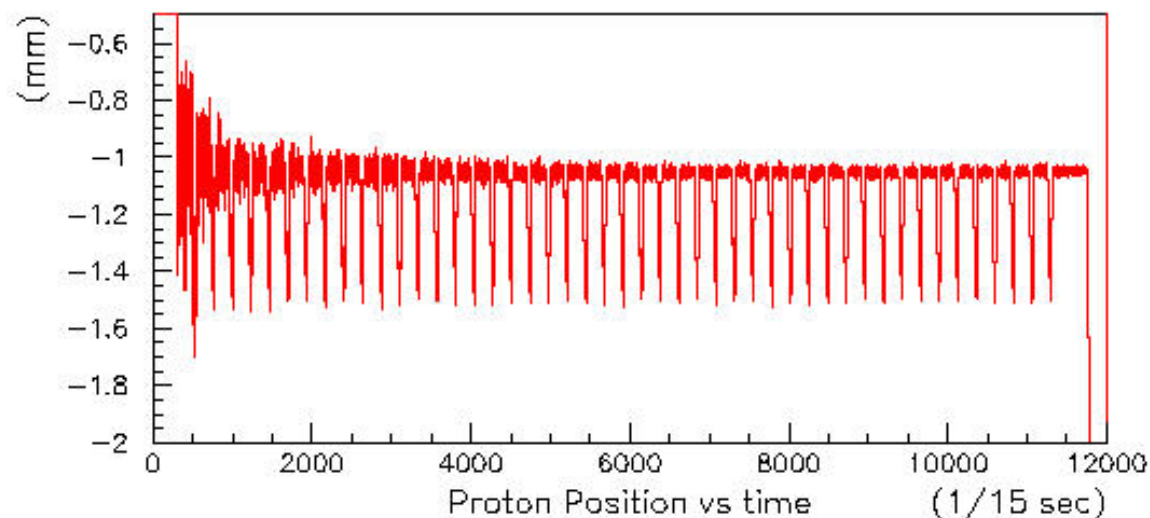
Detail during proton injection and anti-proton injection.

Can see injection bumps during proton injection.
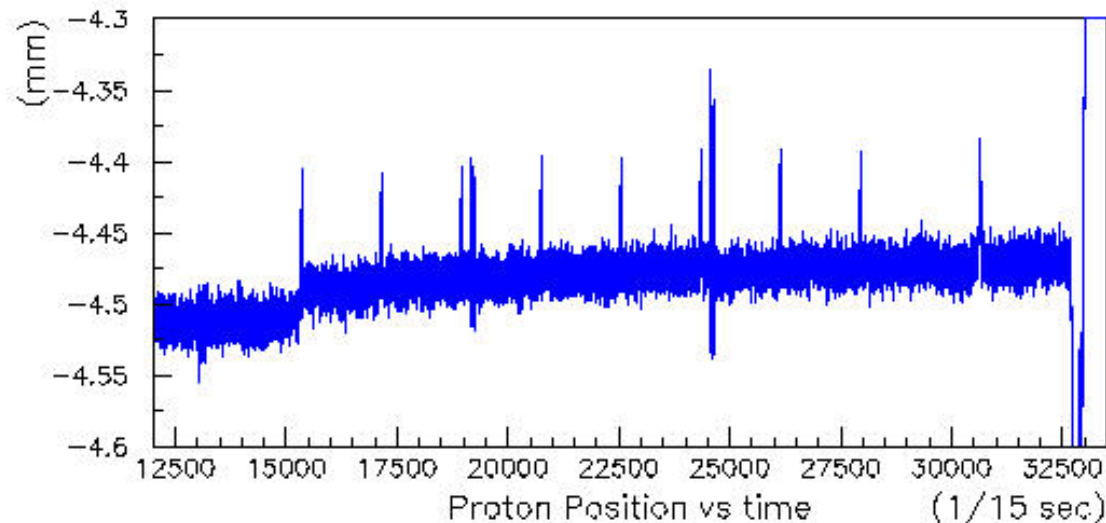
During pbar injection can see injections, cogging and a small instrumental effects.

Pbar Position Measurement Technique

Closed Orbit HA32 Shot on Feb 18, 2005
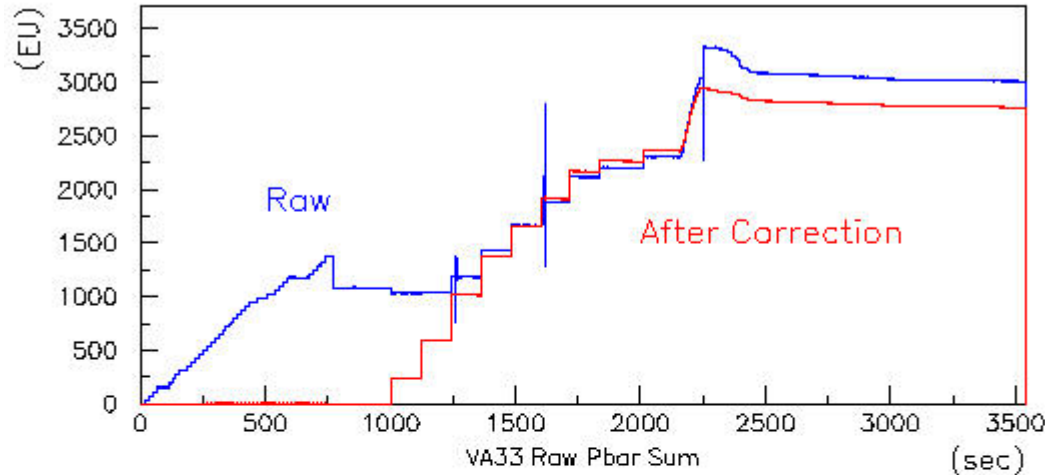
Cancellation of proton contamination on Pbar cables:

$$A'_{Pbar} = A_{Pbar} - aA_P - bB_P$$

$$B'_{Pbar} = B_{Pbar} - cB_P - dA_P$$
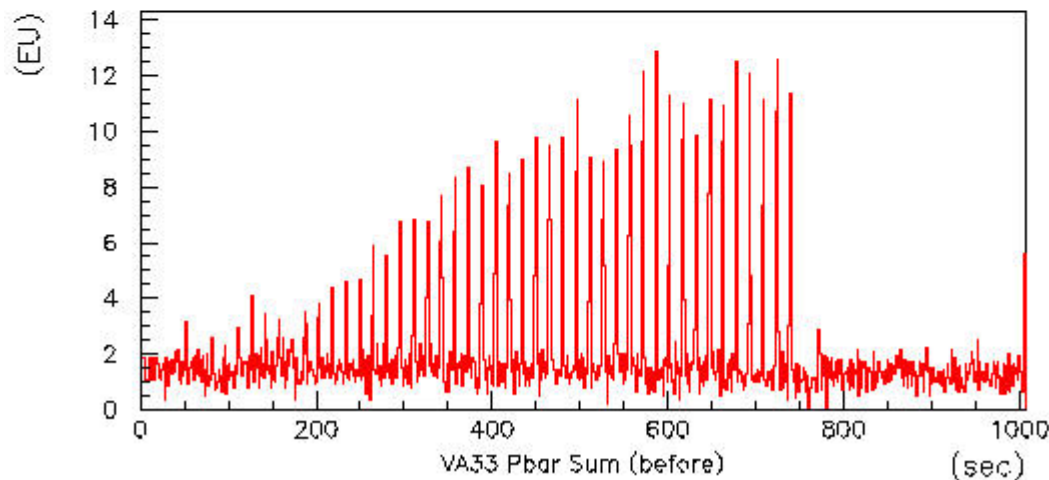
a,b,c,d determined empricially using the opening of the helix.

Using corrected values, compute sum and position as for protons.

Closed Orbit HA32 Shot on Feb 18, 2005

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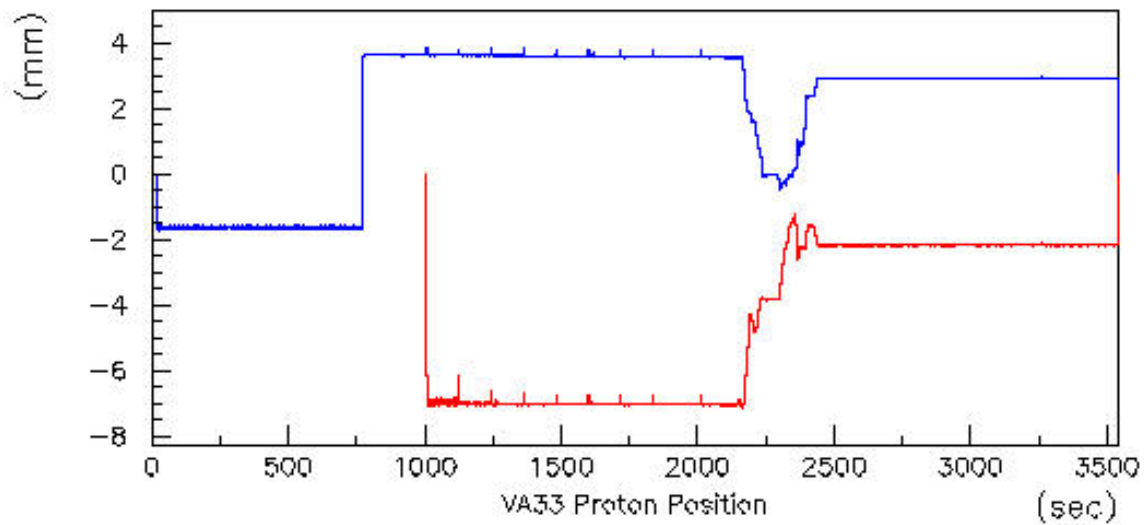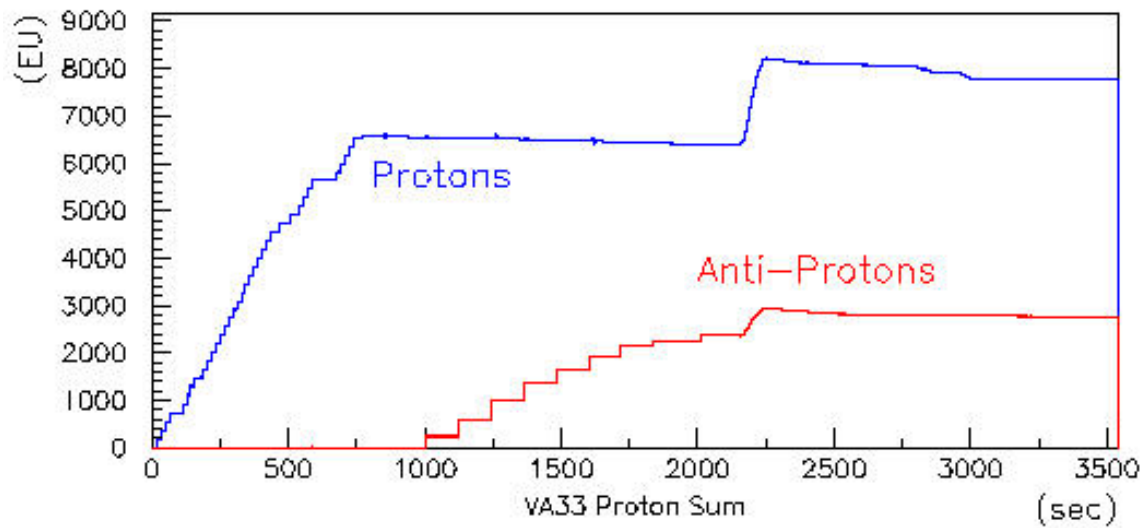
Resolution for A3 BPMs, Feb 14, 2005
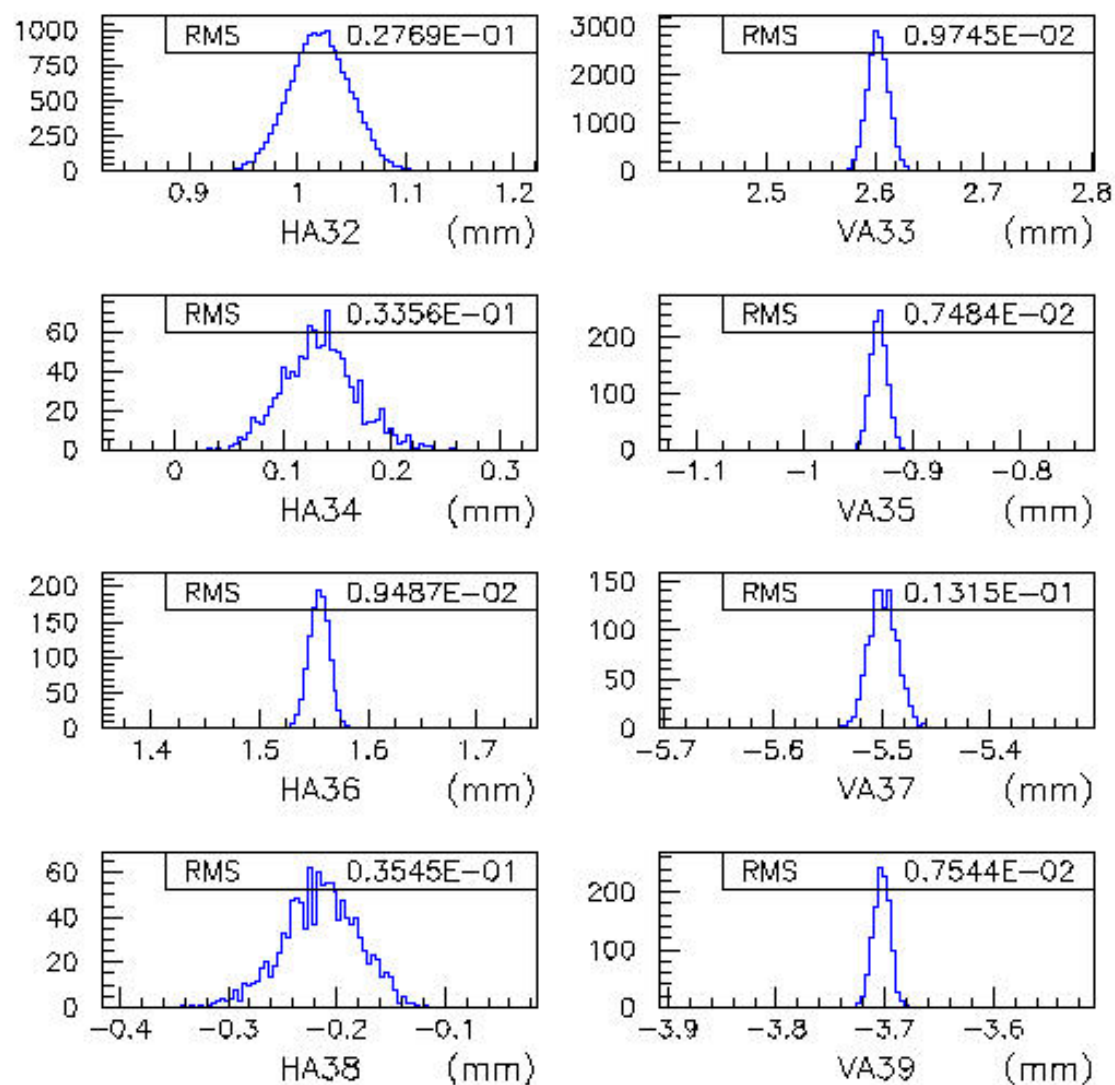
TeV BPM – 36 Bunch Closed Orbit Resolution

#4057:
D33=0.84-A33*1.08
BPM_err=5.2 μm

Correlation plot of closed orbit
data from two BPMs on opposite
sides of ring estimate
resolution to be ~5 microns
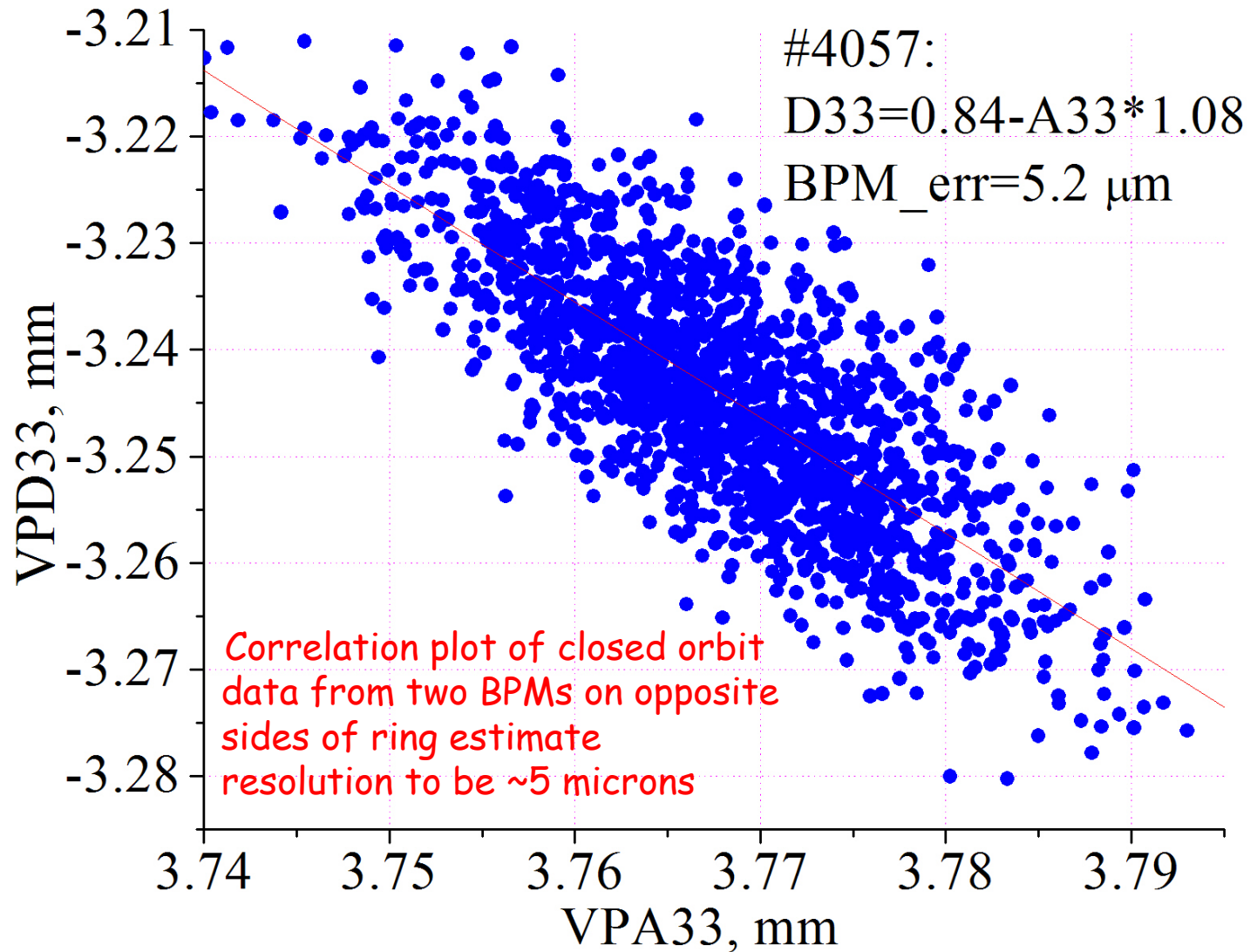
System Performance

- **Turn by turn**
  - **Injection, 150 GeV**
  - **Single bunch or uncoalesced beam**
  - **Can see synchrotron motion, betatron motion, quadrupole oscillations of bunch in the bucket, HV coupling, plus some instrumental artifacts**

Position for H BPMs in A3, Feb 6/05, Coalesced
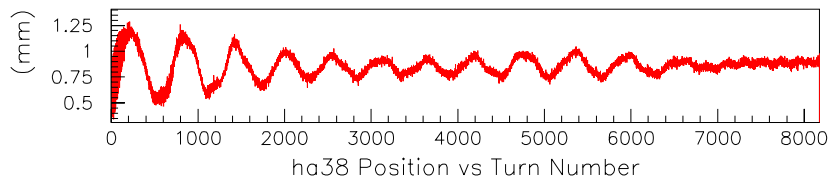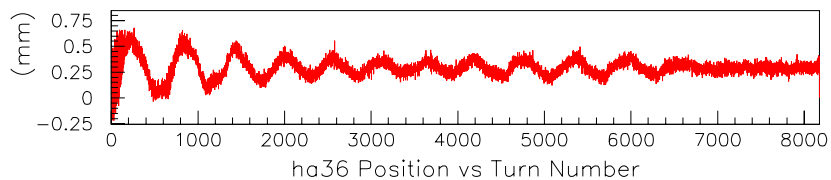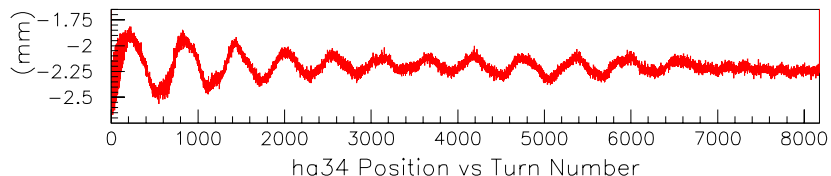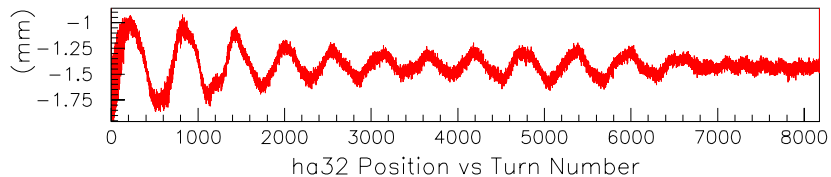
Position for V BPMs in A3, Feb 6/05, Coalesced
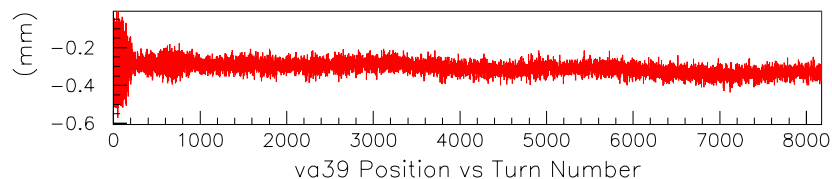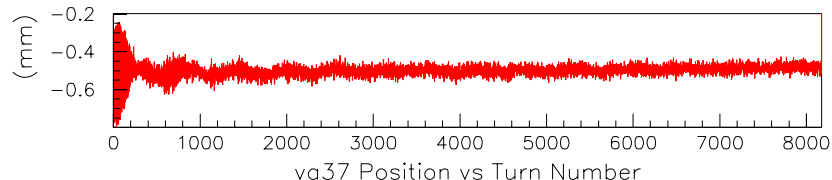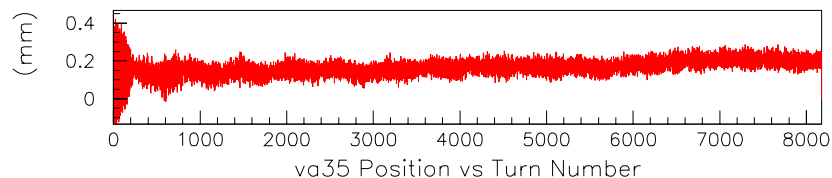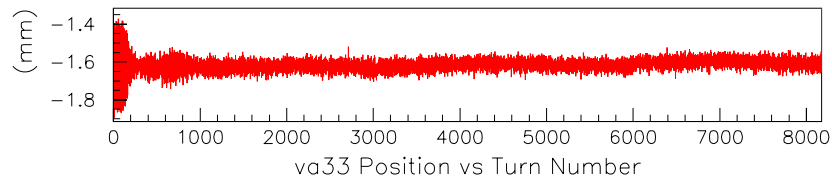
1.1 mm full vertical scale

0.6 mm full vertical scale

- Injection TBT; 150 GeV; 8192 turns.
- One coalesced bunch. HEP shot after all tuning.
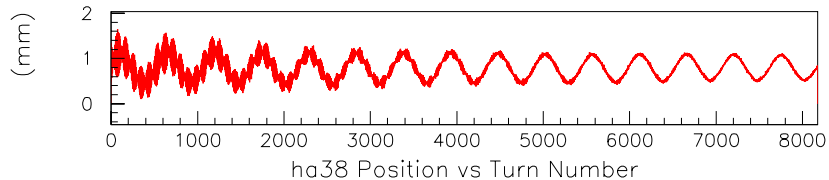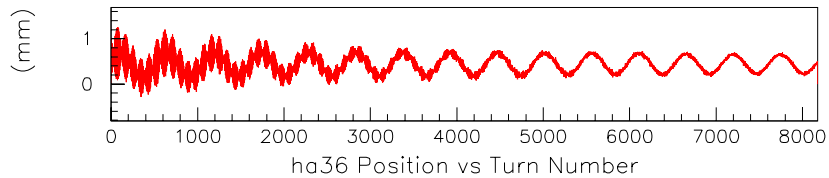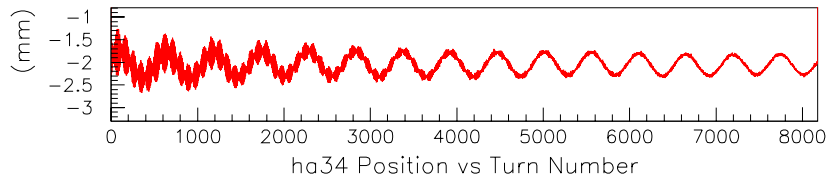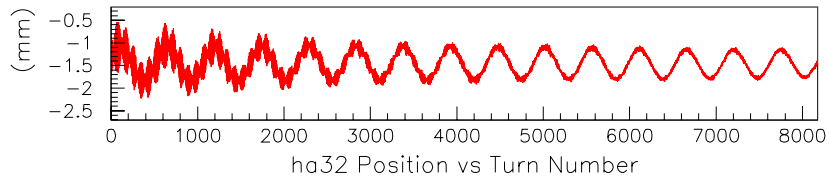
Detail of Mod(FT) for H BPMs in A3, Feb 6/05, Coalesced

Detail of Mod(FT) for V BPMs in A3, Feb 6/05, Coalesced

Noise Measurement

ha32 Mod(FT) vs f   (Hz)

va33 Mod(FT) vs f   (Hz)

ha34 Mod(FT) vs f   (Hz)

va35 Mod(FT) vs f   (Hz)

ha36 Mod(FT) vs f   (Hz)

va37 Mod(FT) vs f   (Hz)

ha38 Mod(FT) vs f   (Hz)

va39 Mod(FT) vs f   (Hz)
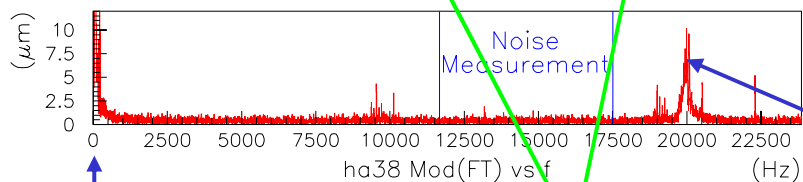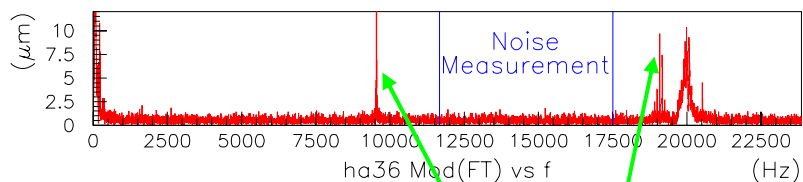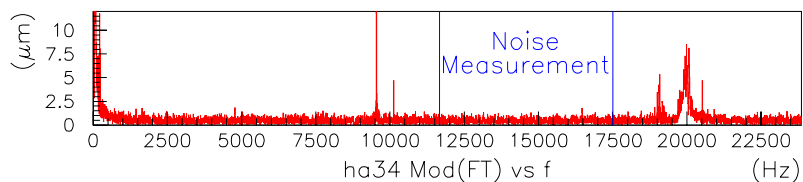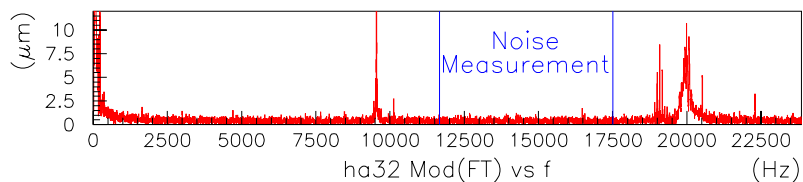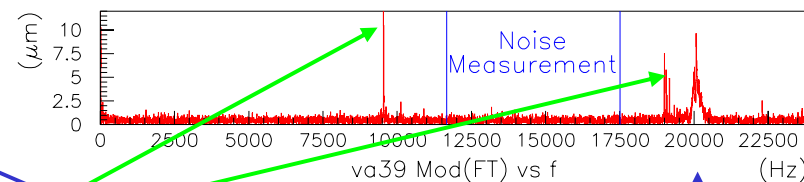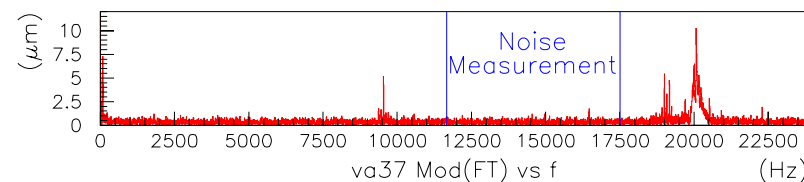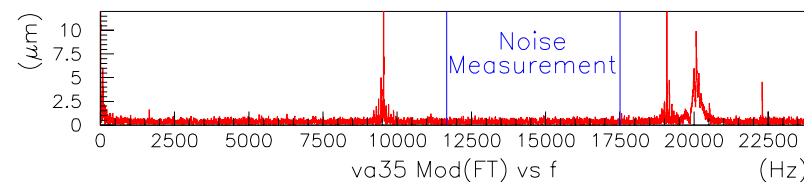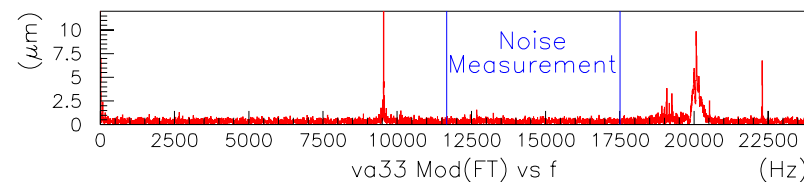
1113 / 5 Artifacts

Bin Size: ~3 Hz

Resolution: 0.3 μm/sqrt(Hz)

Synchrotron Line

Betatron Lines

Detail of Mod(FT) for H BPMs in A3, Feb 6/05, Coalesced
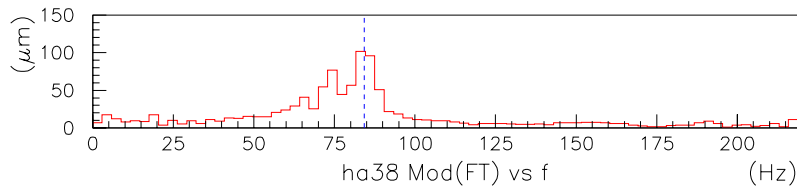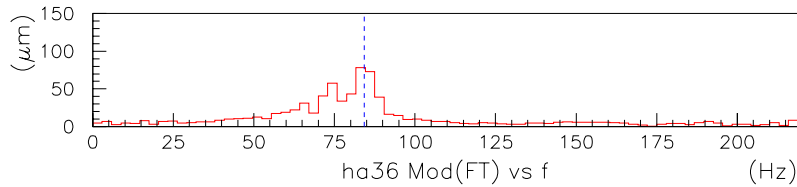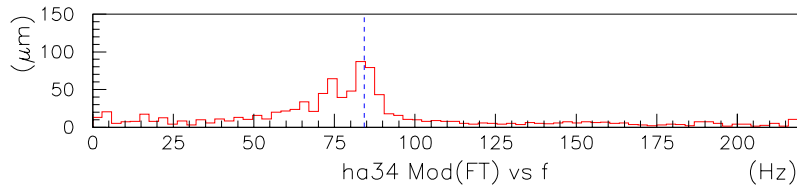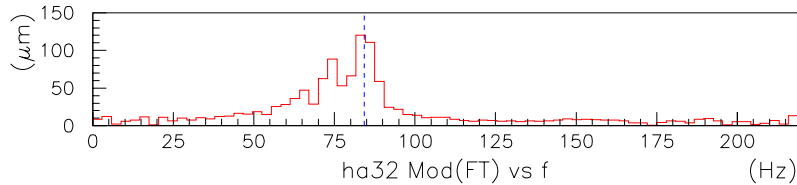
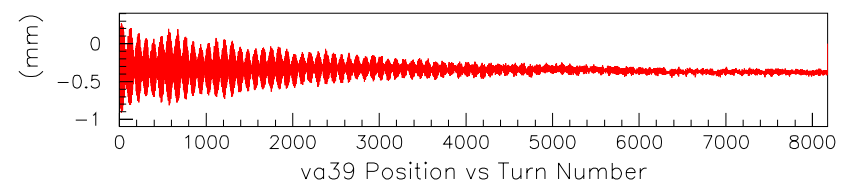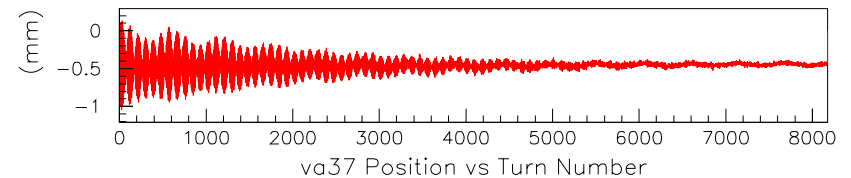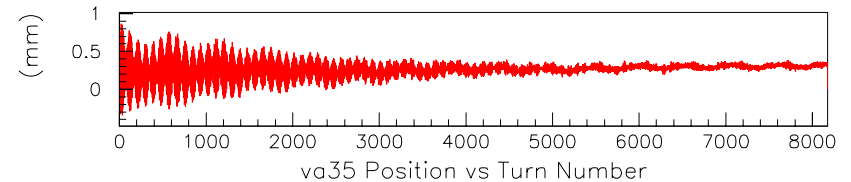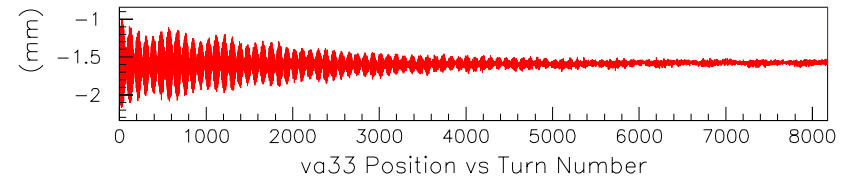Detail of Mod(FT) for V BPMs in A3, Feb 6/05, Coalesced
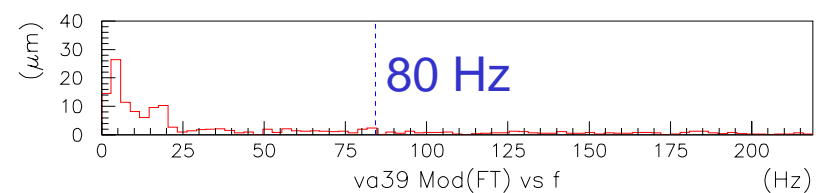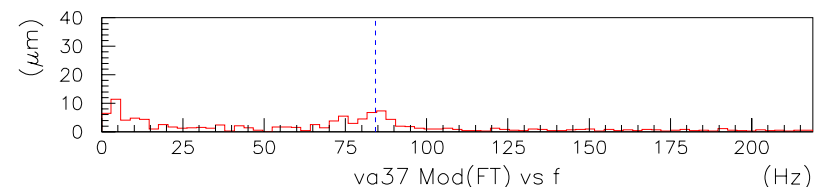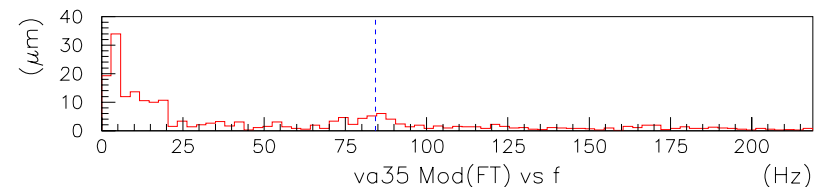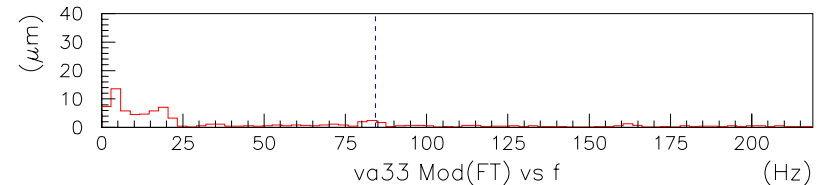
80 Hz

- Synchroton line present in H but not V.
- 150 GeV expected sync frequency: 80 Hz.

Position for H BPMs in A3, Feb 7/05, Uncoalesced

Position for V BPMs in A3, Feb 7/05, Uncoalesced

ha32 Position vs Turn Number

va33 Position vs Turn Number

ha34 Position vs Turn Number

va35 Position vs Turn Number

ha36 Position vs Turn Number

va37 Position vs Turn Number

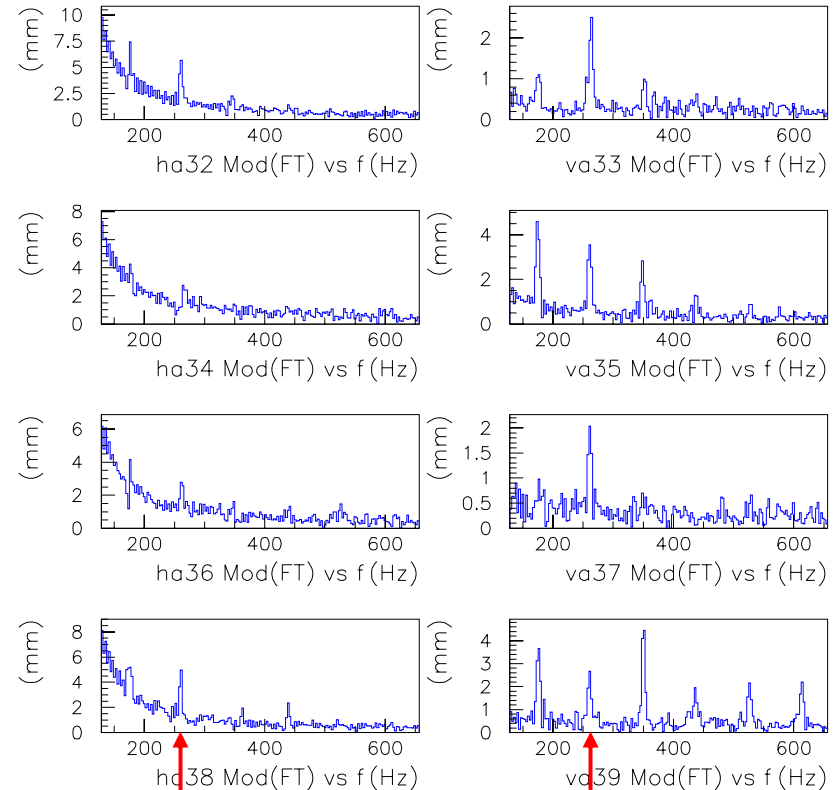ha38 Position vs Turn Number

va39 Position vs Turn Number

- Injection TBT; 150 GeV; 8192 turns.
- Uncoalesced beam. Tuneup shot with large injection mismatches.

Position for HA32 and VA33, Feb 7/05, Uncoalesced

Fourier Transforms of Position Data, Feb 7/05, Uncoalesced
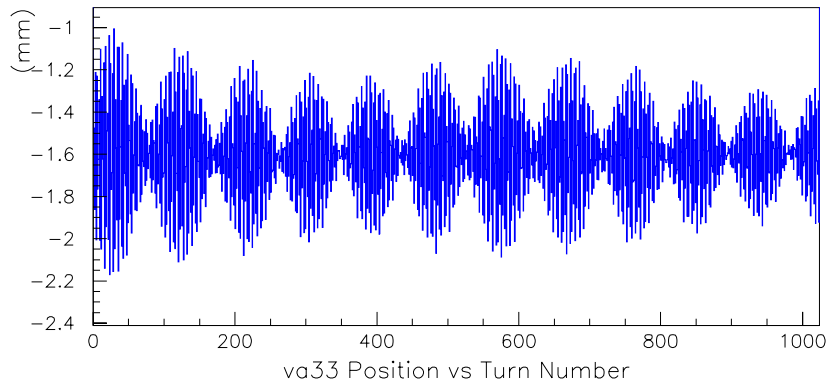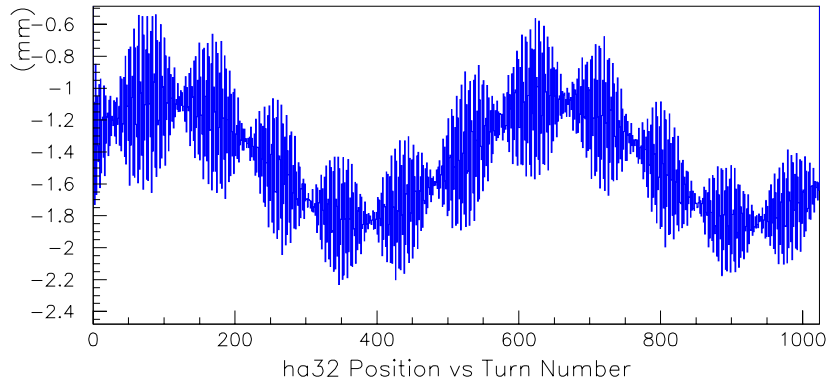
- HV coupling is clear.
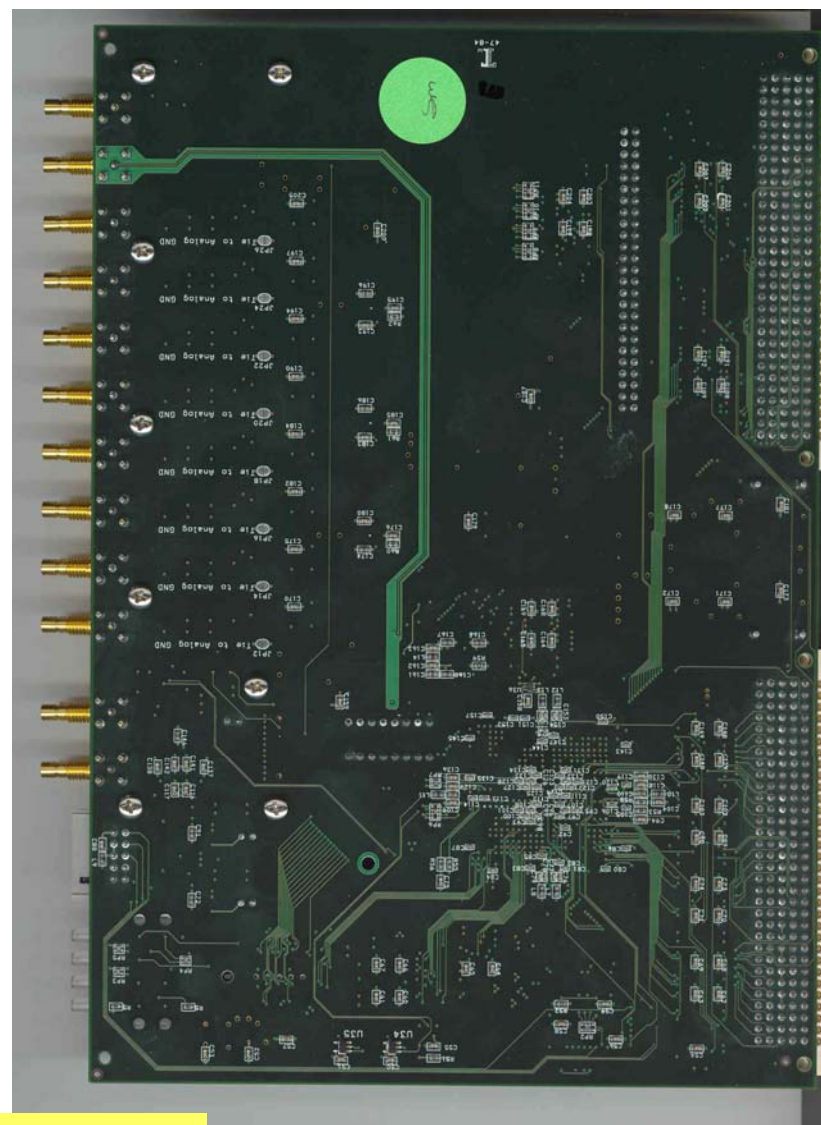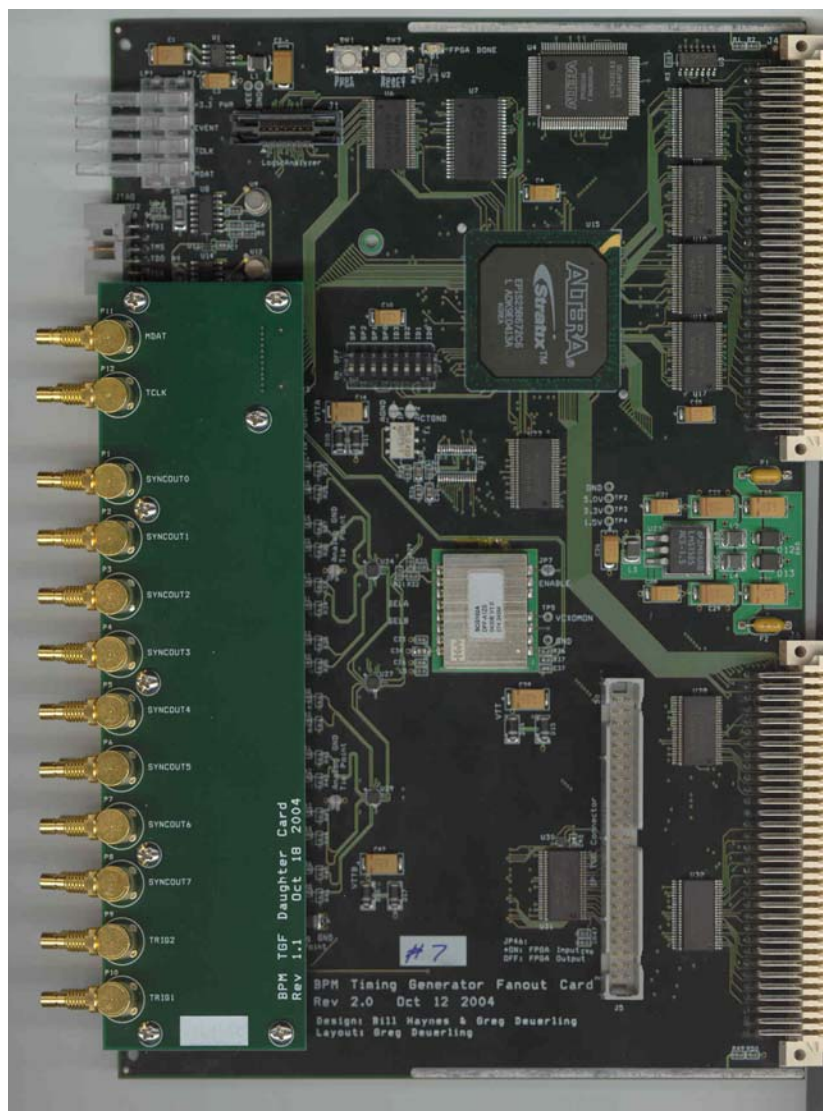- Frequency of envelope is about 260 Hz.

HV Coupling Frequency

Conclusions

- **The Tevatron BPM Upgrade has been successfully installed and commissioned.**

- **Work continues on final calibration, diagnostics, pbar measurements, documentation.**

- **Thanks to the work of many people in the Computing and Accelerator Divisions at Fermilab.**
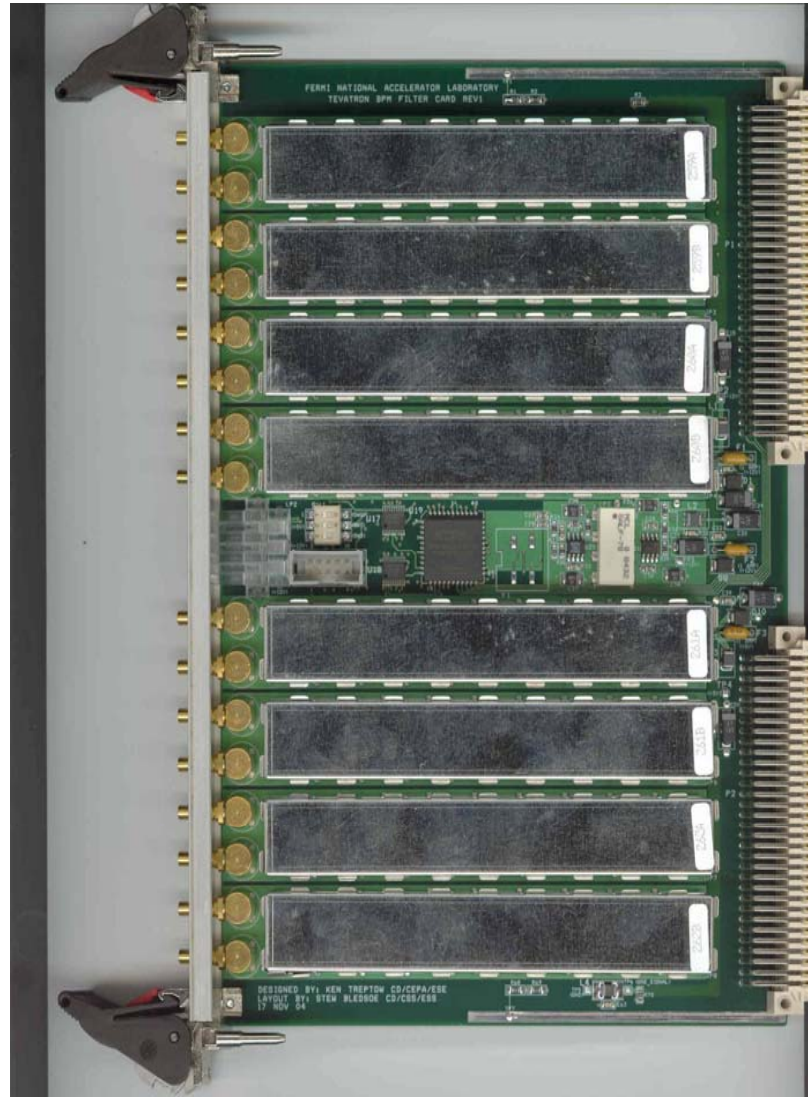
-

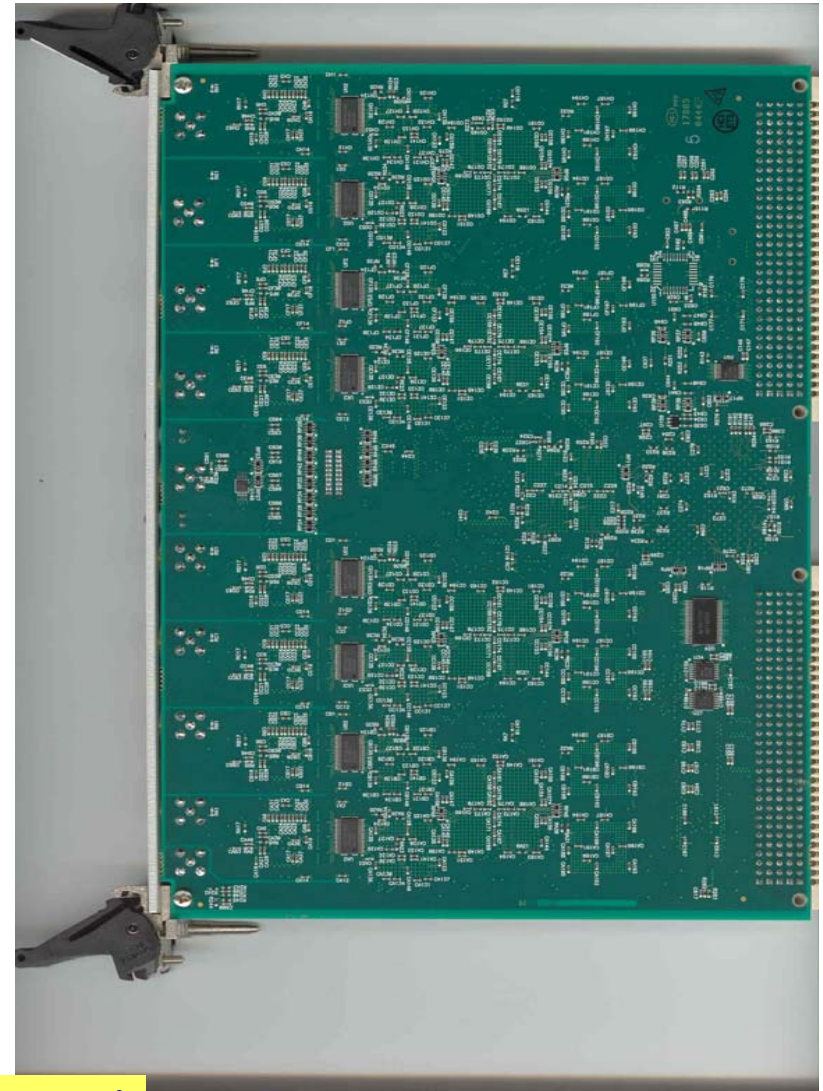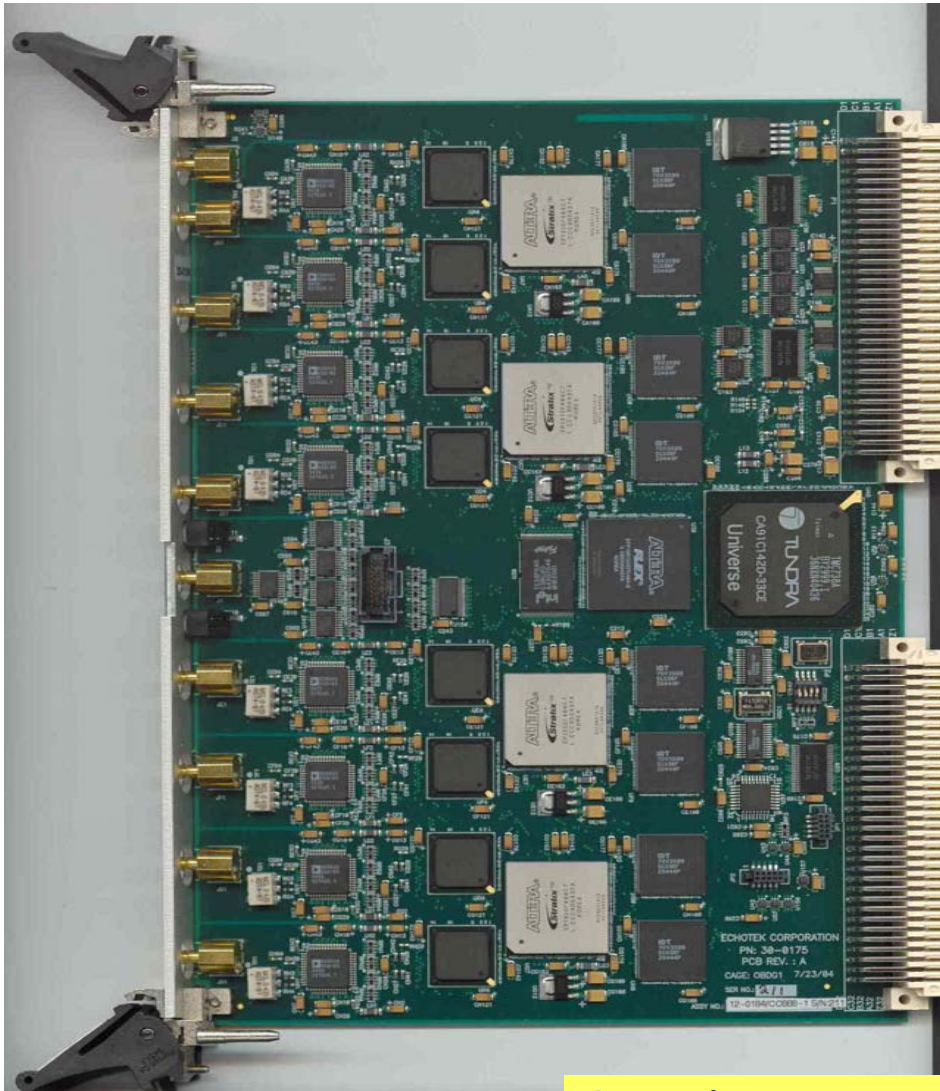# Extra slides

Timing Board

Production Board

Filter Board

- 8 channels
- 53 MHz band-pass filter
- Attenuation Circuit
- Relays/53 MHz diagnostic signal
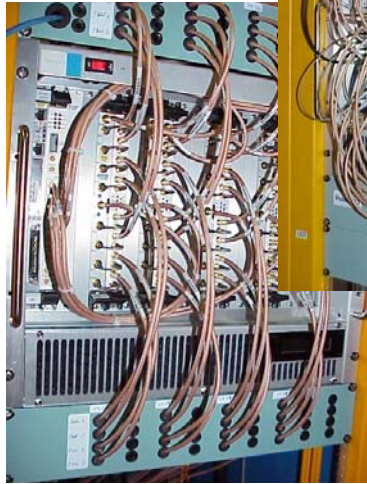- Shielding

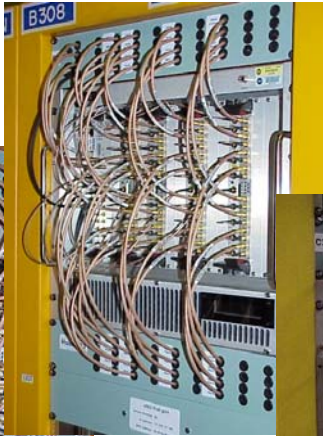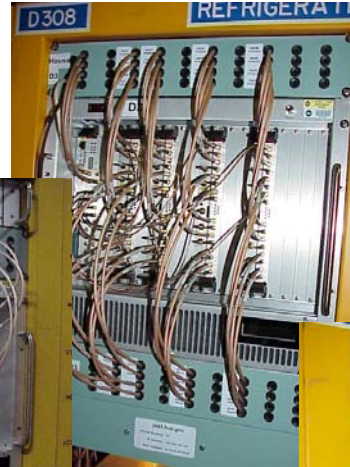**Production Board**

Echotek Board
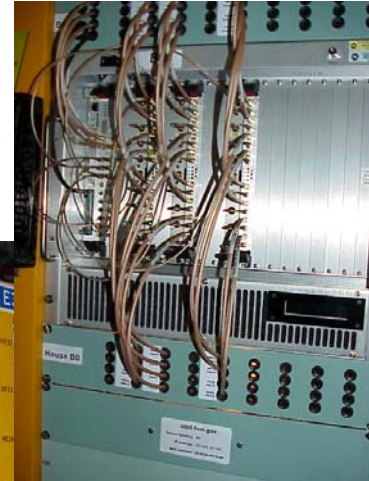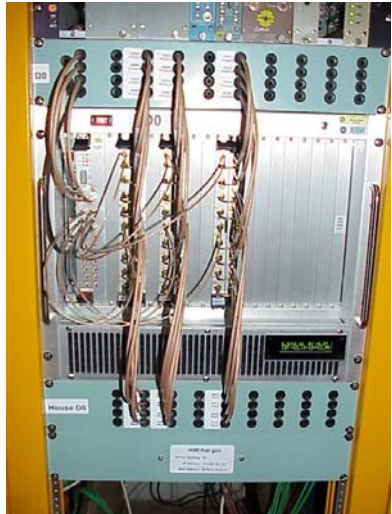

Production Board

Systems are going in!

B3
2/10/05

A3
11/22/04

C3
2/23/05

D3
3/08/05

E3
3/11/05

B0
3/23/05

D0
3/24/05
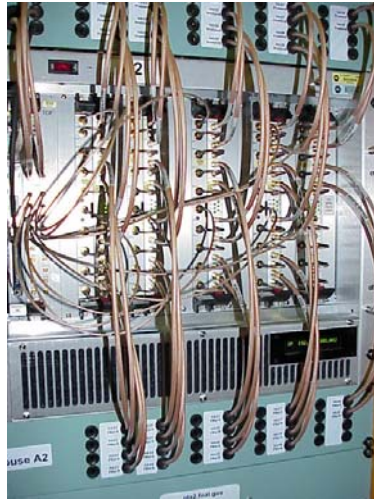
A2
3/30/05
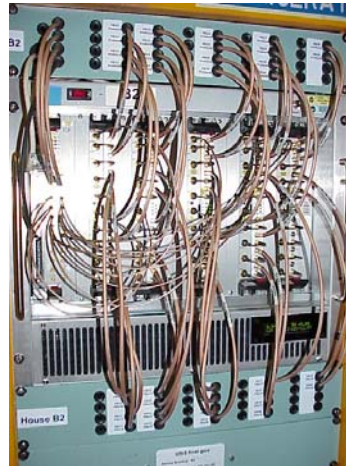
B2
3/30/05
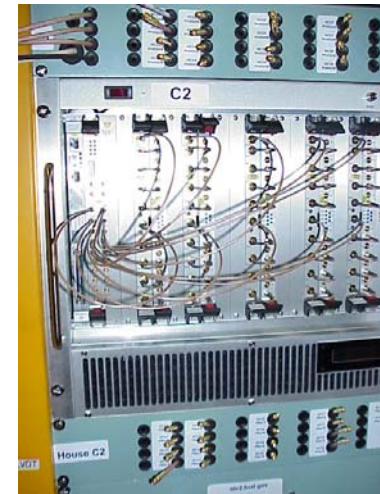
C2
3/30/05
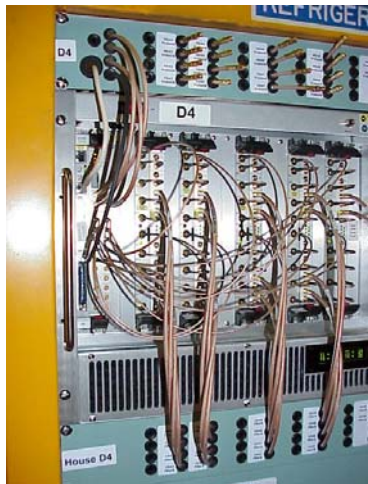
D2
3/30/05
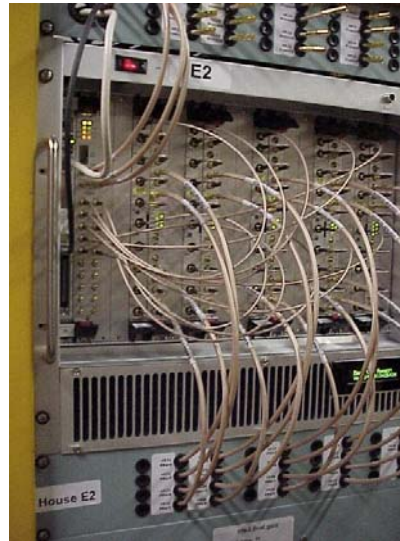
E2
3/30/05

One Day's Work!

E2
4/8/05

F2
4/8/05
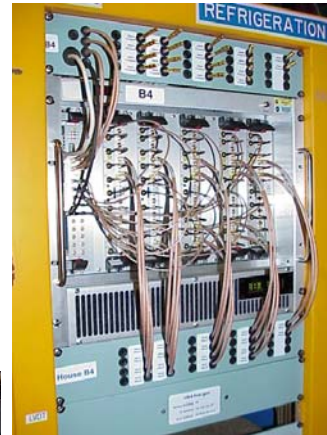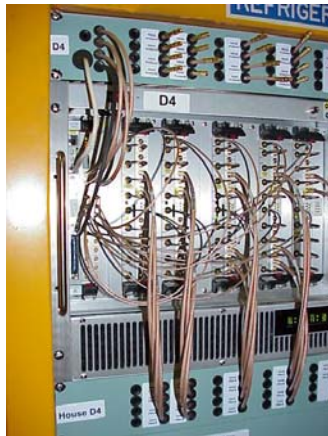
D4
4/8/05

A4
4/8/05

B4
4/8/05

C4
4/8/05

A1
4/11/05

E4
4/11/05

B1
4/15/05

C1
4/15/05

D1
4/15/05

E1
4/15/05
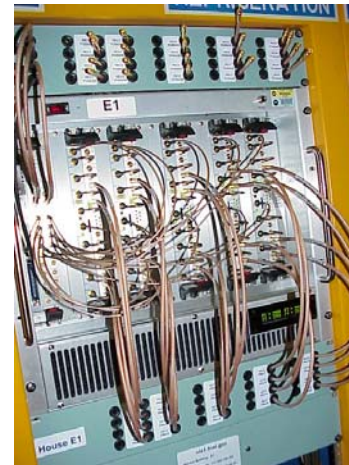
Alternative Block Diagram

- BPM signals

- Analog Filters & Diagnostics
- Sampler, Downconverter and Digital Filters
- VME crate controller
- Data out ACNET
- Control & Diag.
- Clock&Gate
- BSync Clk
- Control
- Interrupts
- TeV Timing Signals
- TClk Clock
- BPM Timing Module
- TeVR FClk
- Software Timing Module
- TClk
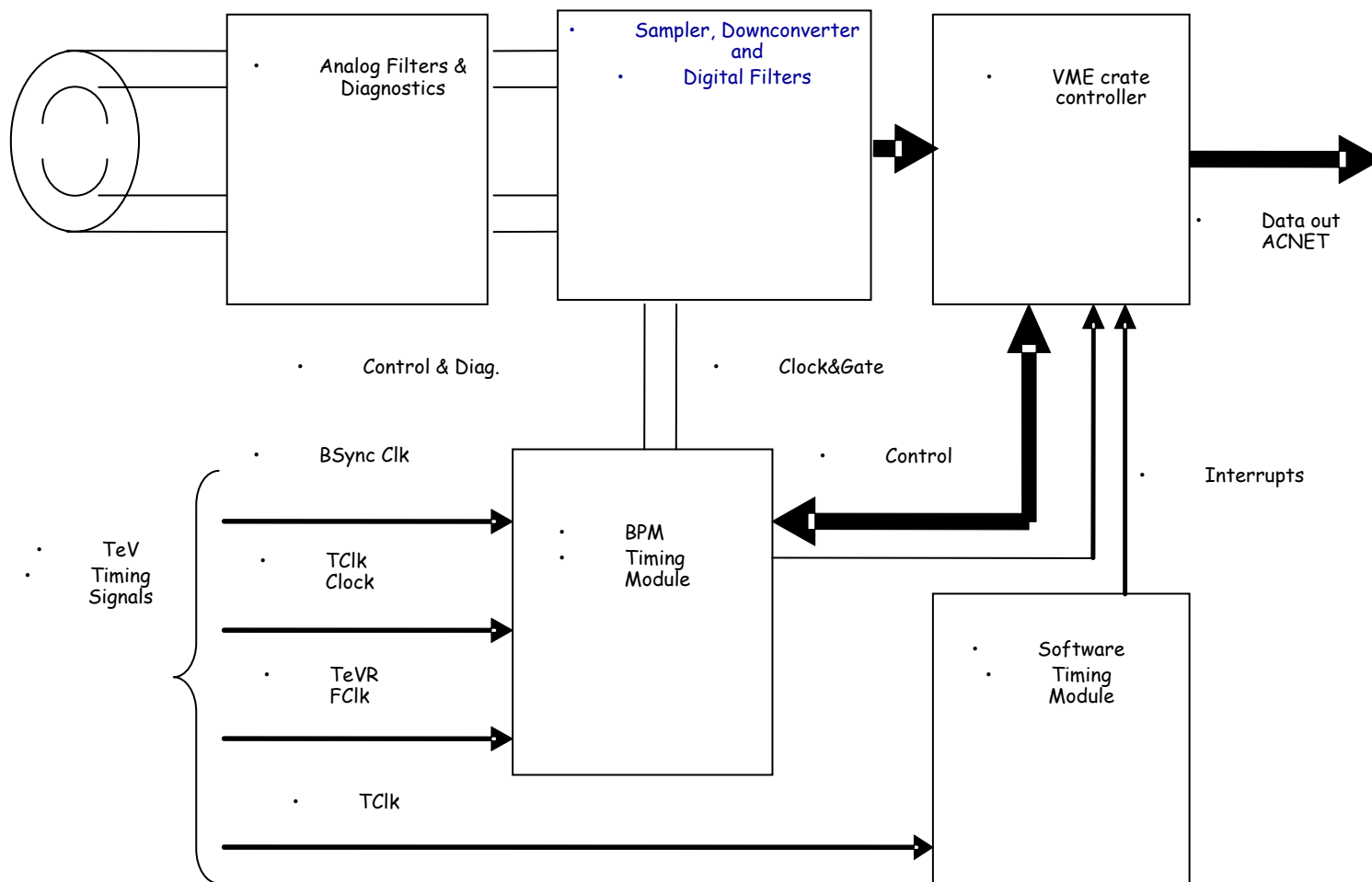
Hardware Components

- **Echotek Digital Signal Receiver (150)**
  - Commercial 8 channel 80 MHz 14 bit ADC, DDC, FPGA
  - Exact or similar boards are common to Recycler, Transfer Lines, NUMI, MI BPM projects
- **Front-end Filter Board (150)**
  - 53 MHz band-pass filter, 10 or 20 dB attenuator, relays for diagnostic signal
- **Timing Board (38)**
  - Provides clocks and triggers for Echotek
  - Provides 53 MHz diagnostic signals
- **MVME 2400-0361 Processors, VME subracks, Crate monitoring, cables, test stands, test signals, controls network.**
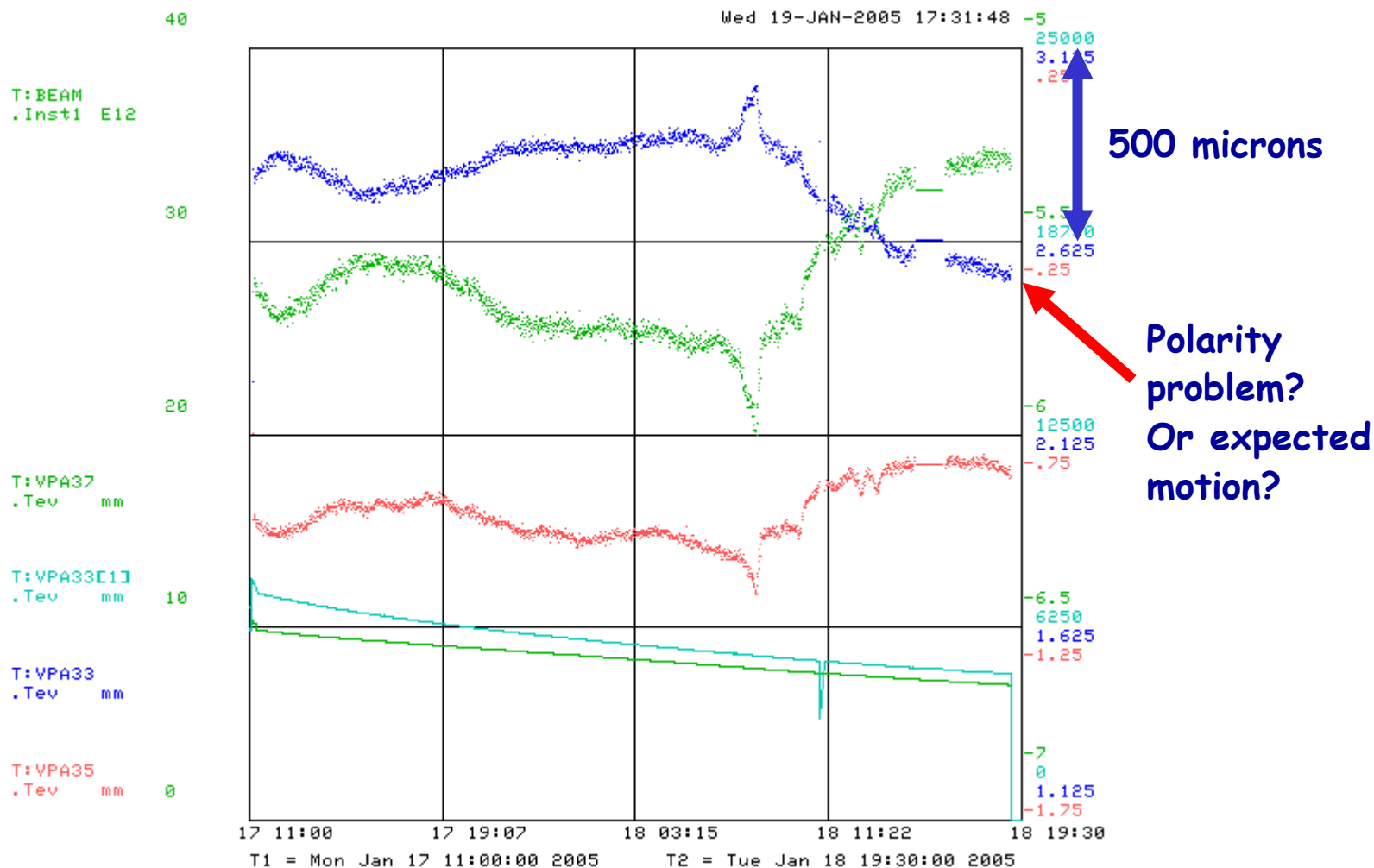
Software Overview

- **Front-end**
  - Processes Echotek output to provide
    - **Closed orbit**
    - **Turn-by-turn**
    - **Injection first turn**
  - **Manages data collection and modes of operation.**
- **Online/console applications**
  - **Moves data into controls system and applications, libraries and databases.**
  - **Essentially all applications have been modified to use the new data.**
- **Offline/calibration**
  - **Provides necessary deconvolution (pbar) and corrections to ensure accuracy and precision of the system.**
  - **pbar measurements will be available at the front-end.**
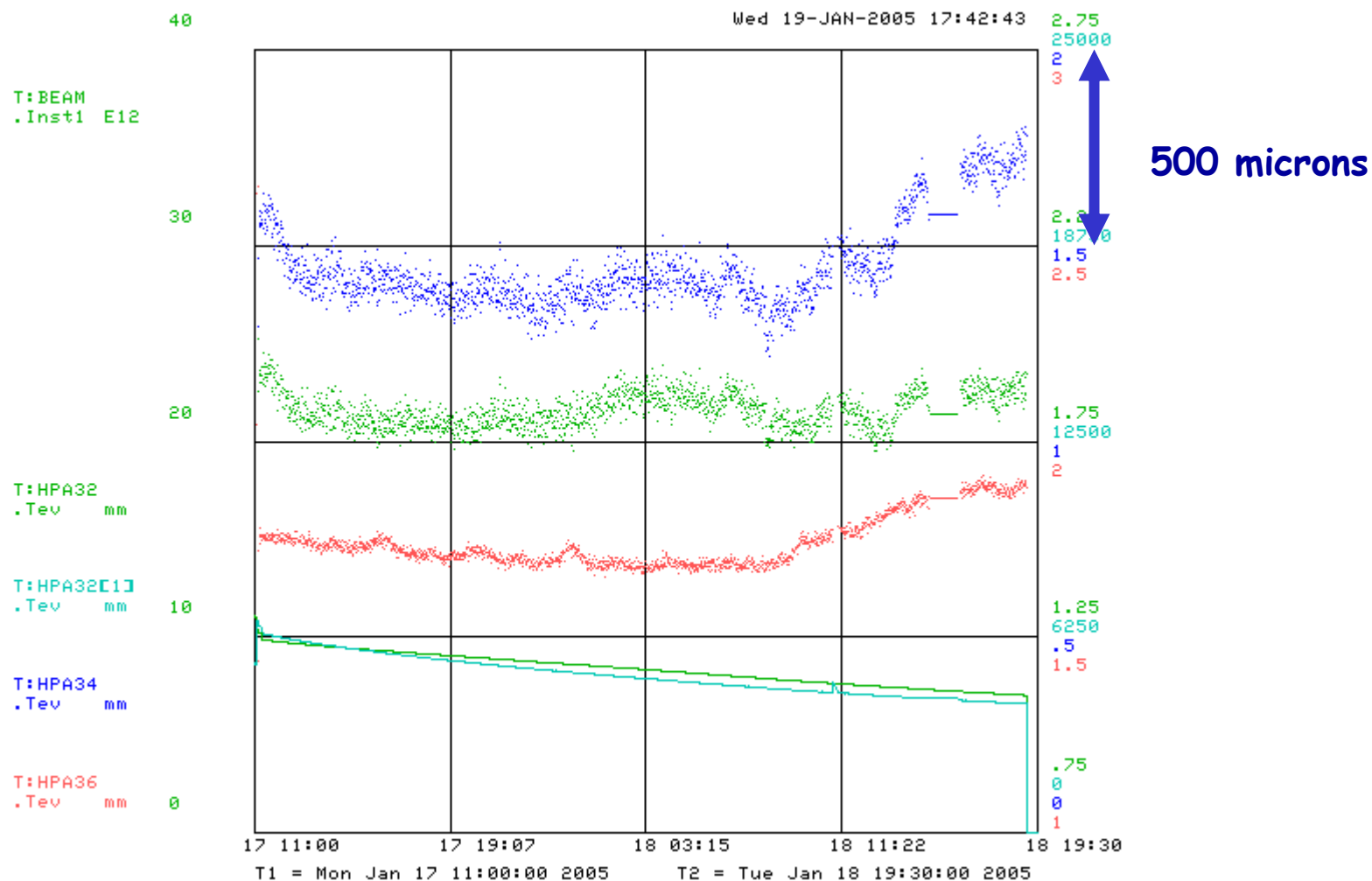
A3 result – pbar, injection
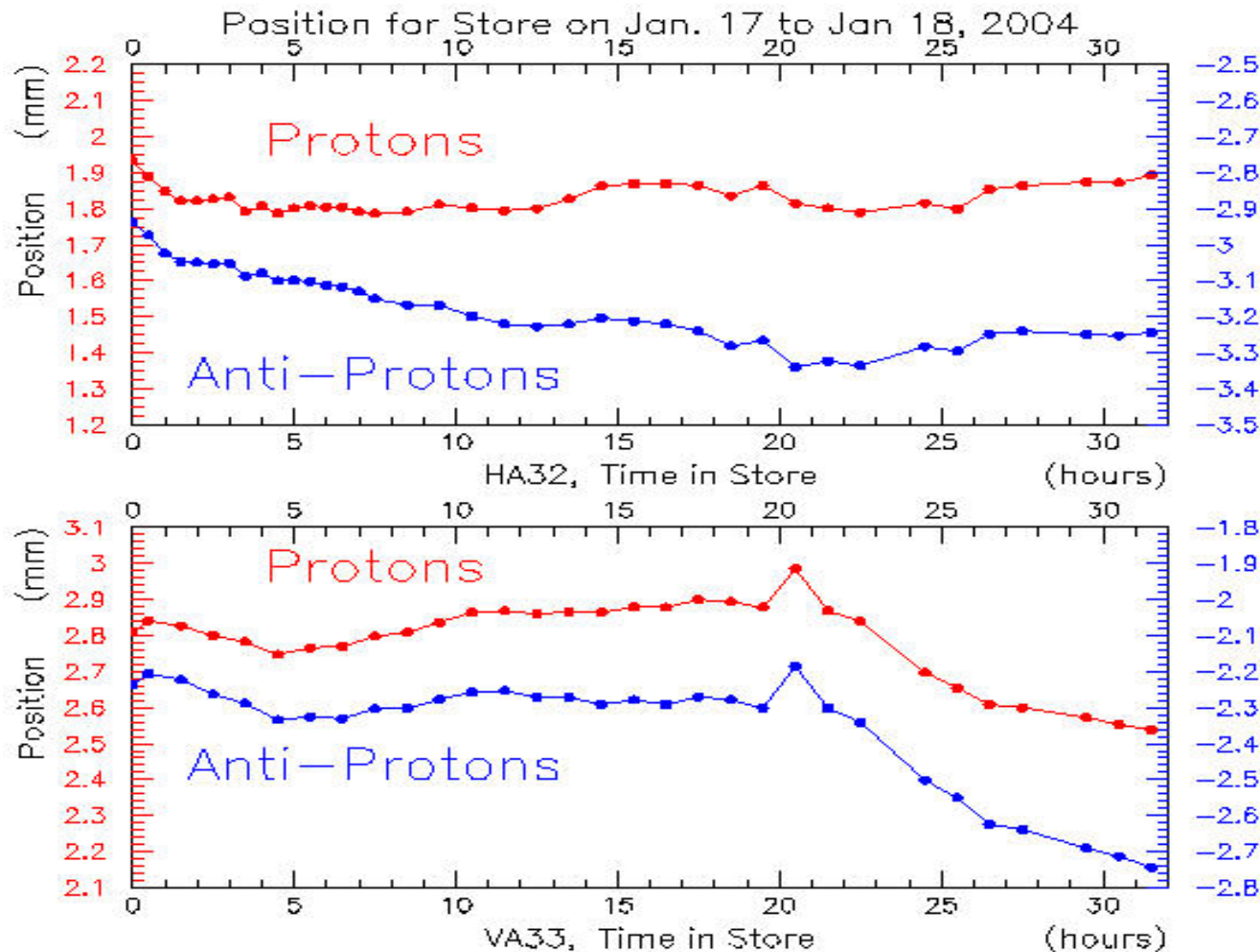

Reverse Helix Study, VA35 December 8, 2004

Predicted Pbar position

Measured pbar position
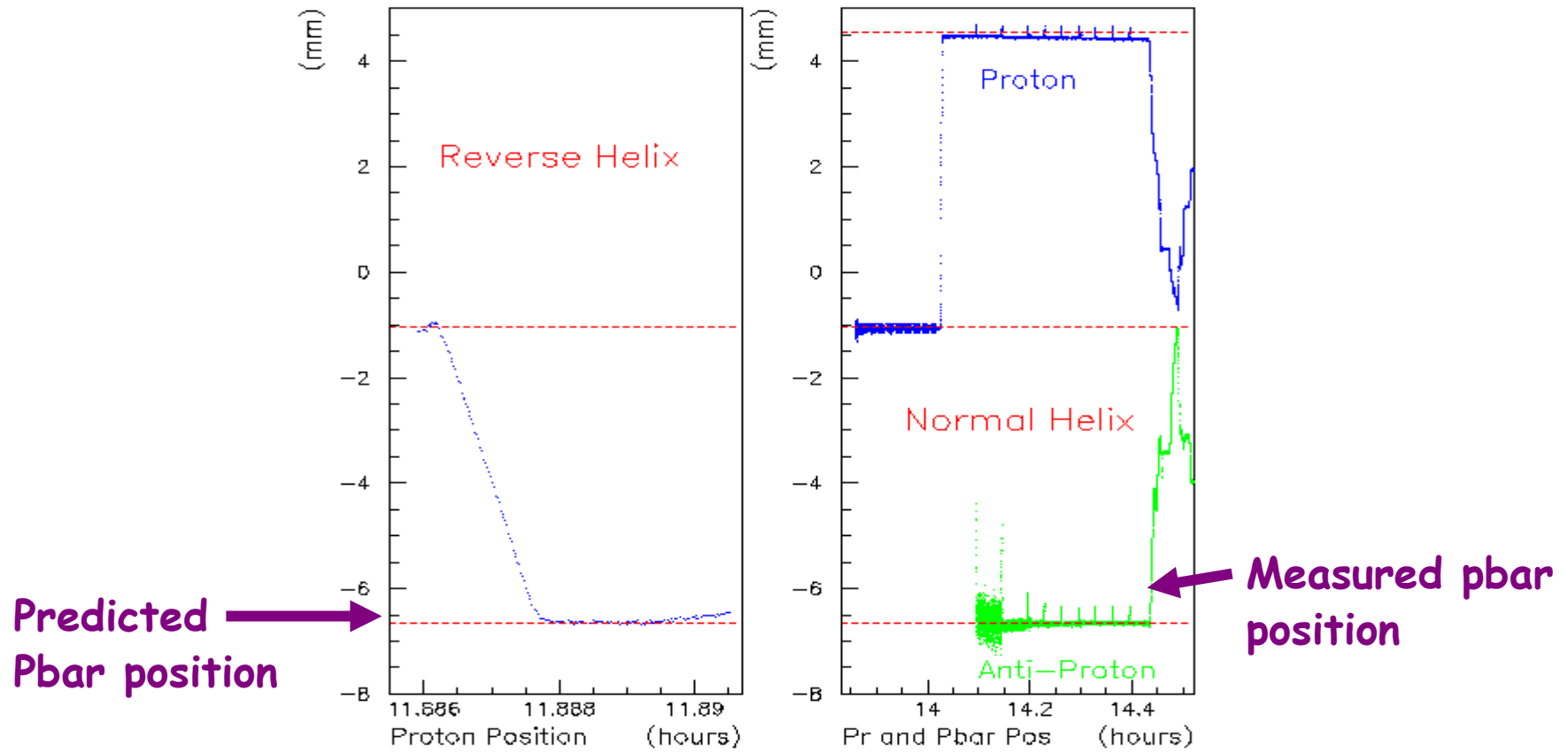
Recent Store (Monday 1/17/05) Vertical

May 16-20, 2005 — Stephen Wolbers — PAC05, Knoxville, TN — 40
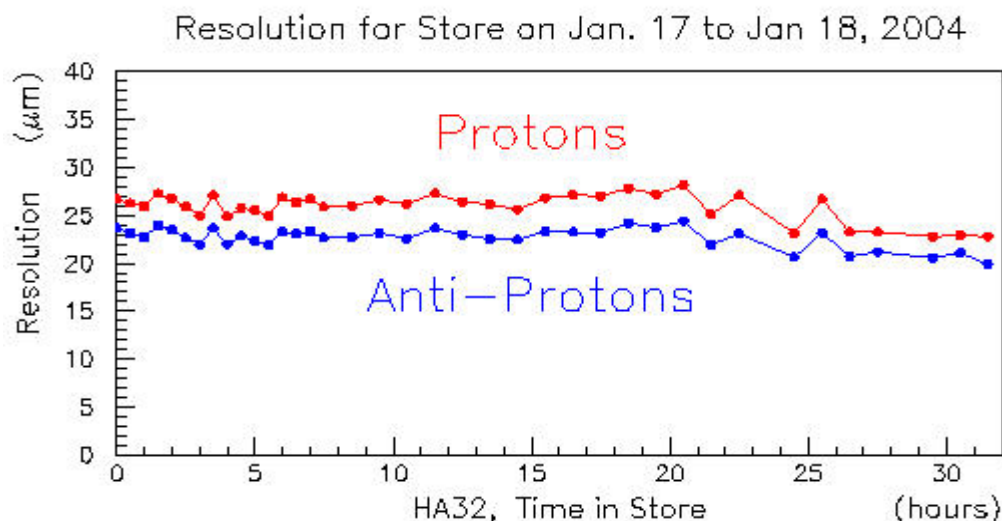
Same store - horizontal

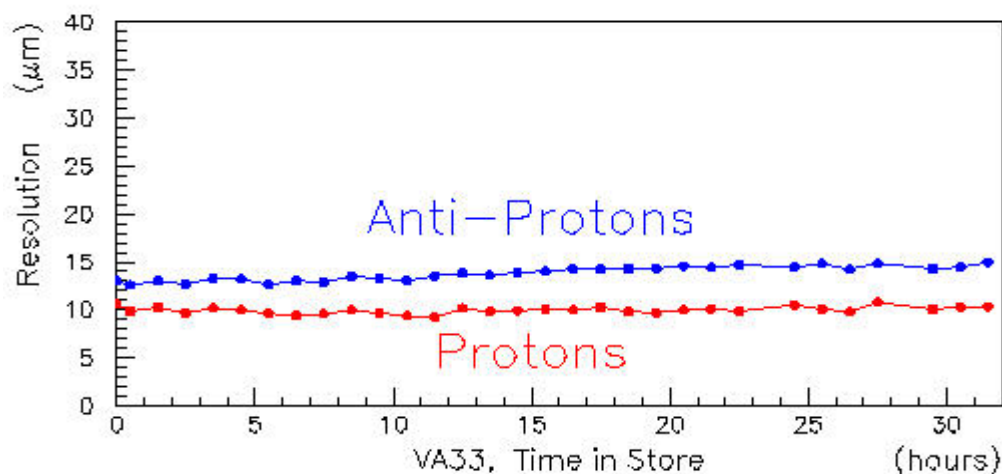# p and pbar positions during 1/17/05 store

Early results- Still need to Analyze to see If it makes Sense.

P and pbar resolutions (closed orbit) during 1/17/05 store

Horizontal ~20-25 μm (thought to be due to beam motion)

Vertical ~10-15 μm